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(71) Applicant(s)
Baker Hughes Inc
(Incorporated in USA - Delaware)
3900 Essex Lane, Suite 1200, PO Box 4740, Houston, Texas 77210-4740, United States of America

(72) Inventor(s)
Edward J Zisk Jr

(74) Agent and/or Address for Service
Murgitroyd & Company
Scotland House, 165-169 Scotland Street, GLASGOW, G5 8PL, United Kingdom

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E21B 43/12

(52) UK CL (Edition T)
E1F FLF FLK F304

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GB 2361017 A
GB 2351748 A
GB 2314866 A

(58) Field of Search
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INT CL[7] E21B
Online: WPI, EPODOC, PAJ

(54) Abstract Title

Sand screen with active flow control

(57) A tool for regulating the rate of fluid flow from an earth production zone comprises a flow control zone 23 through which fluid from the production zone is channelled. Preferably the flow control zone 23 is formed in an annular space between a central bore 11 and a surrounding production tubing 21. Within the flow control zone is a flow control device which selectively restricts the flow of fluid through it, and two sets of ports 24, 26, the first upstream of the device and the second downstream. Both sets of ports allow fluid to flow into the central bore 11 to carry the fluid to the surface and are selectively opened and closed. The control device comprises circumferentially placed stator columns 30 in the flow channel which can selectively interlock with sliding gate plugs 36, such that when they are engaged fluid cannot flow past, and the first set of ports 24 are open. Disengagement of the stator columns 30 and gate plugs 36 simultaneously closes the first set of ports 24 and allows fluid to flow beyond the stator columns. Downstream the fluid encounters a helically wound wall 28 which acts to reduce the fluid flow rate, before passing through the second set of ports 26 into the central bore 11. In an intermediate position both sets of ports are closed. In alternative embodiments the ports are opened and closes by electrically actuated solenoid valves or valves controlled by shape memory alloy, which reacts to the temperature of the fluid.

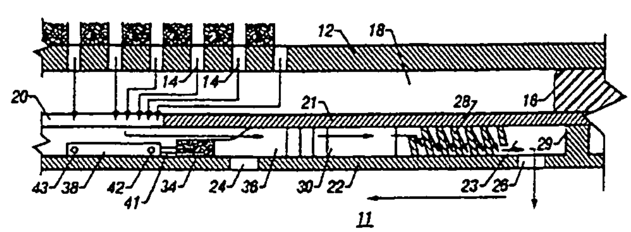

FIG. 2

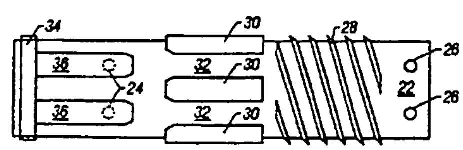

FIG. 5

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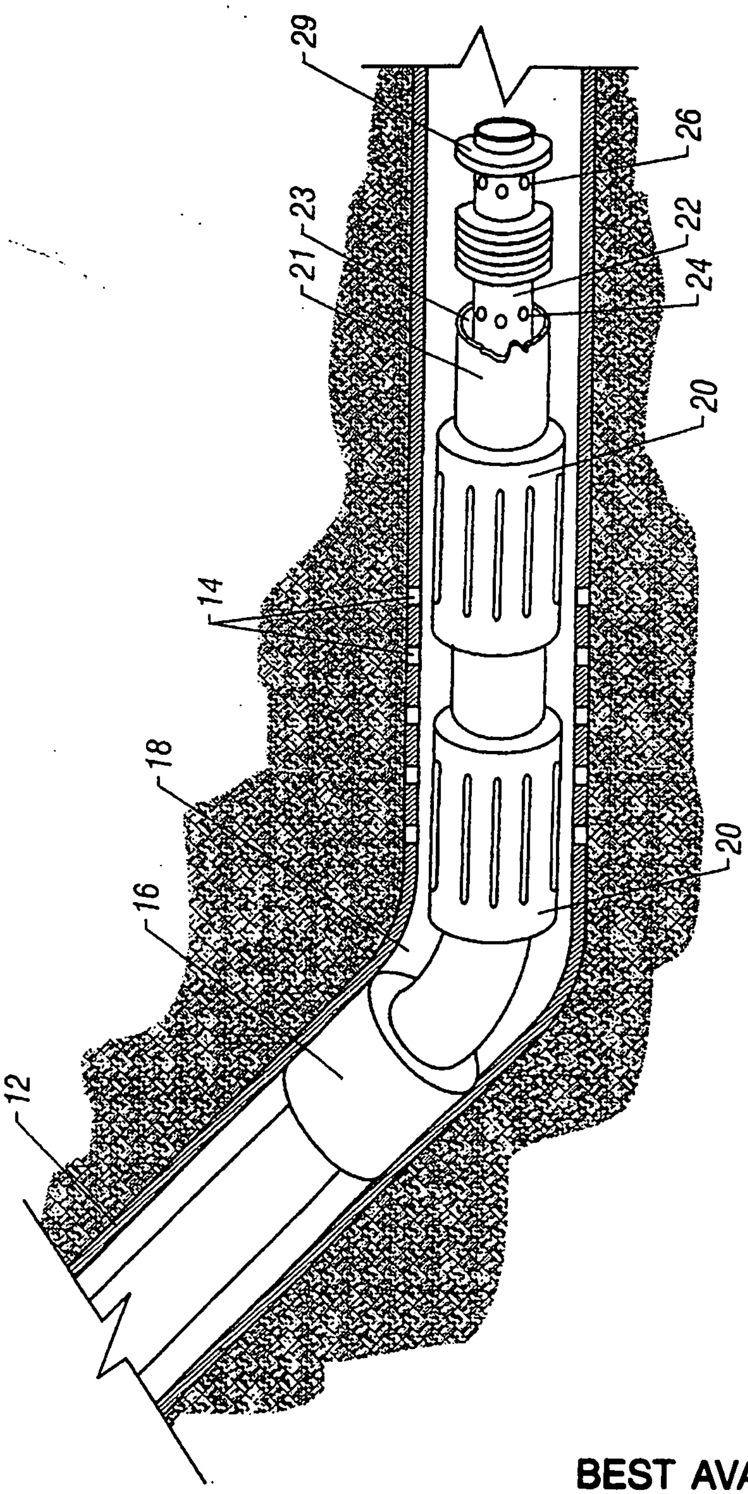

FIG. 1

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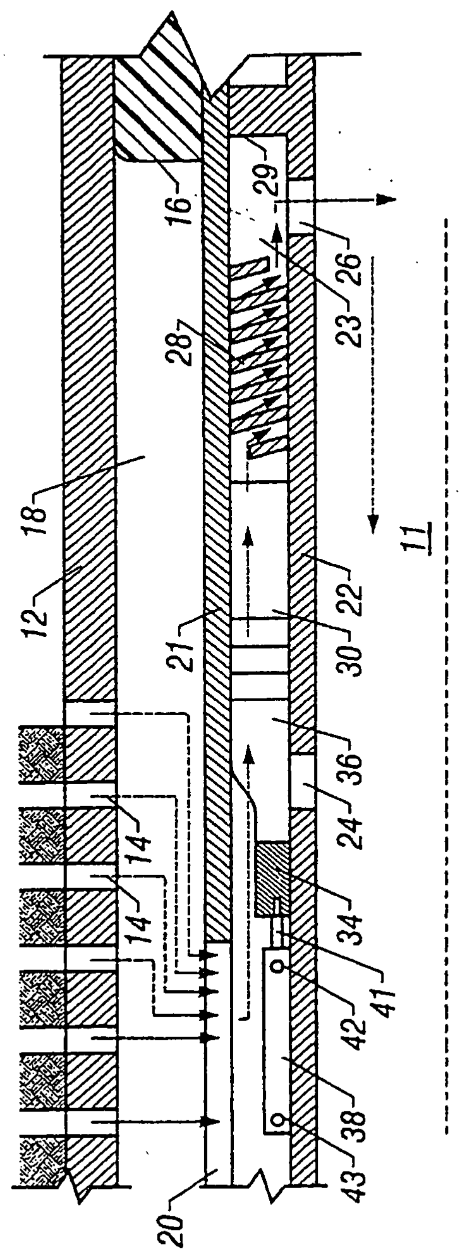

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FIG. 2

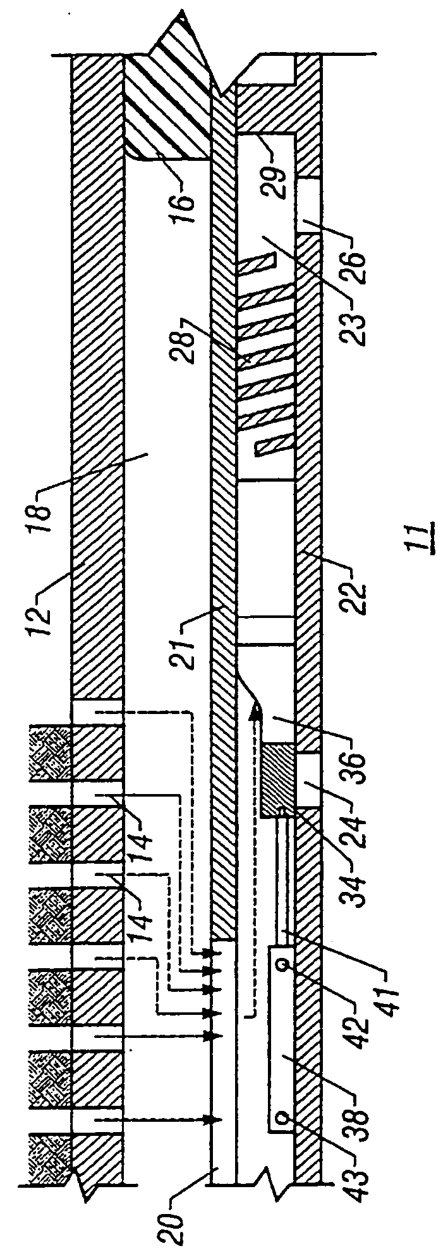

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FIG. 3

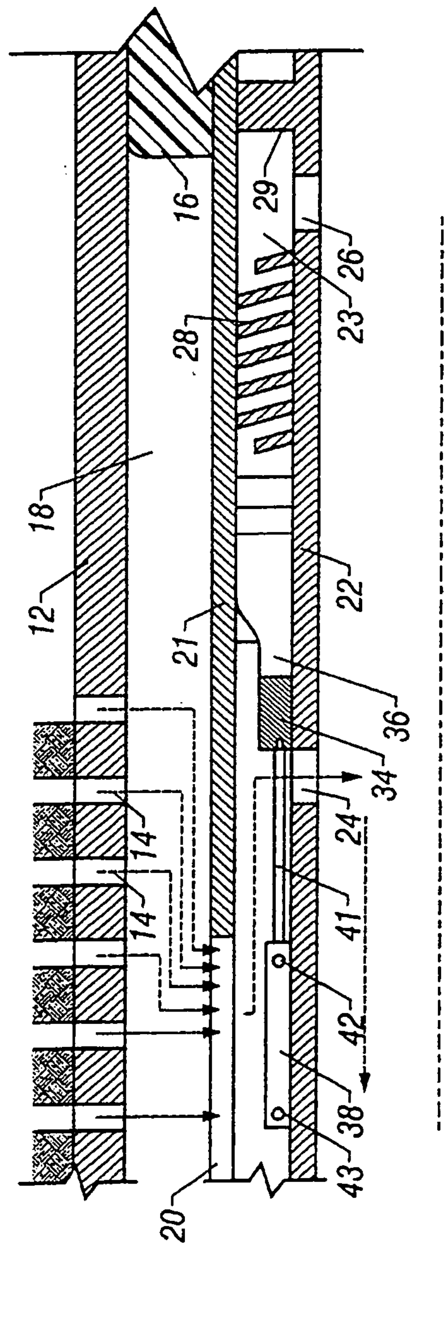

FIG. 4

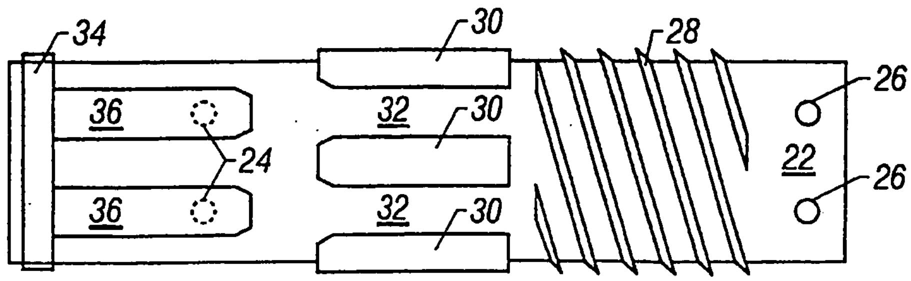

FIG. 5

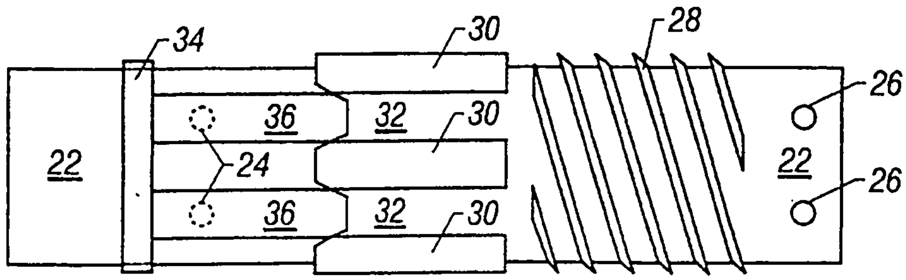

FIG. 6

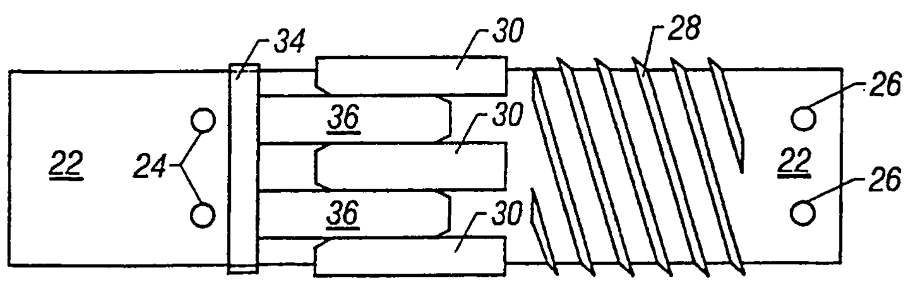

FIG. 7

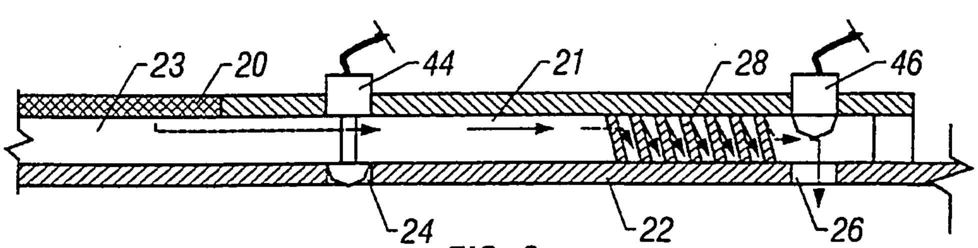

FIG. 8

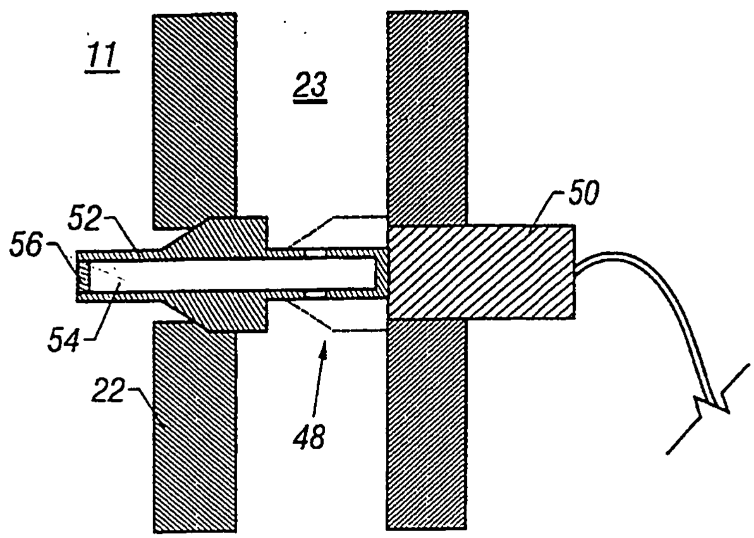

FIG. 9A

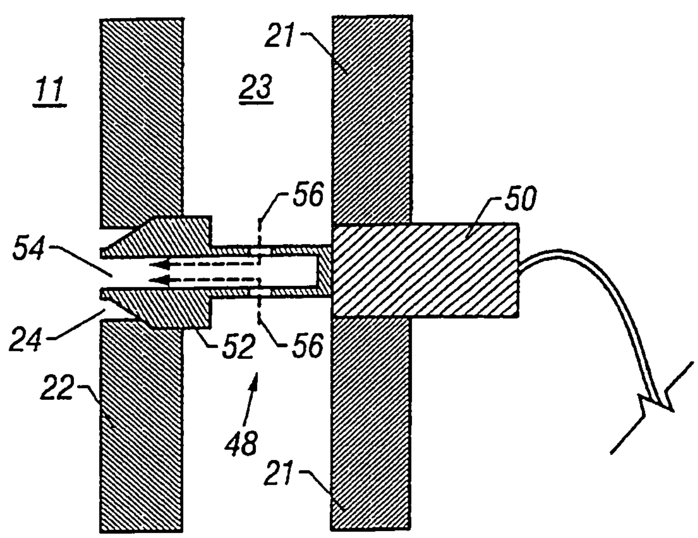

FIG. 9B

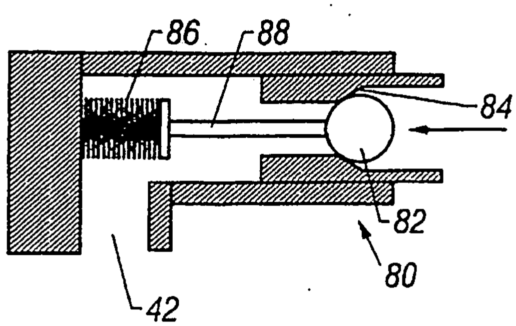

FIG. 10A

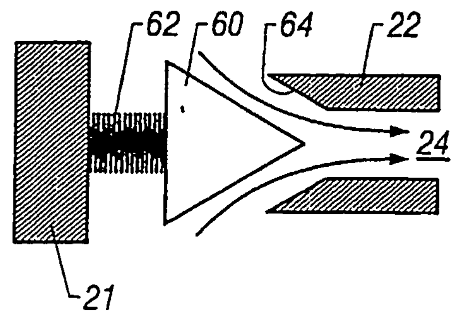

FIG. 11A

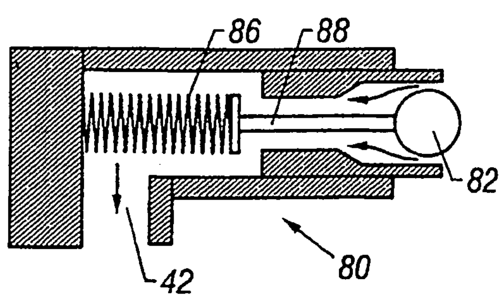

FIG. 10B

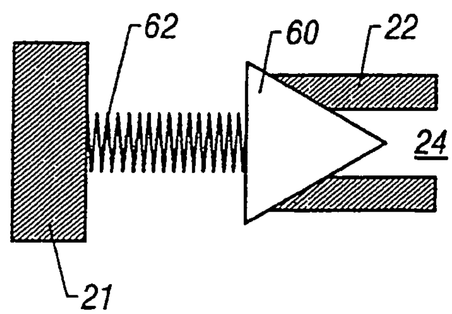

FIG. 11B

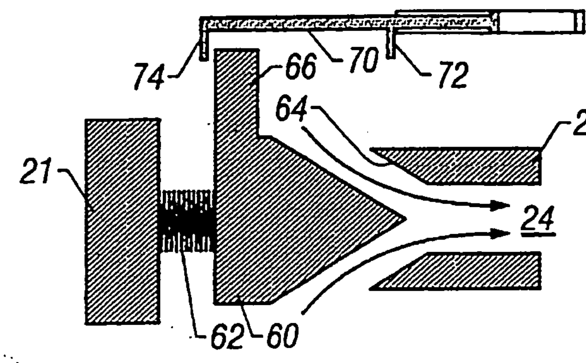

FIG. 12A

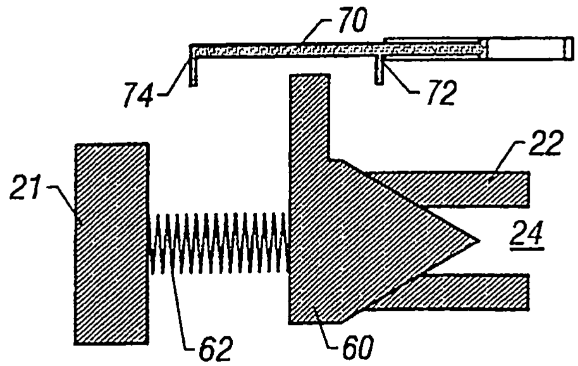

FIG. 12B

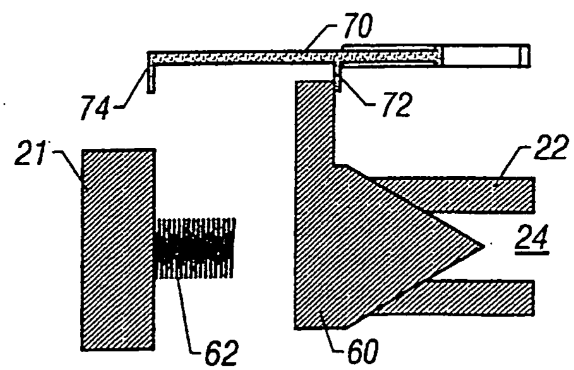

FIG. 12C

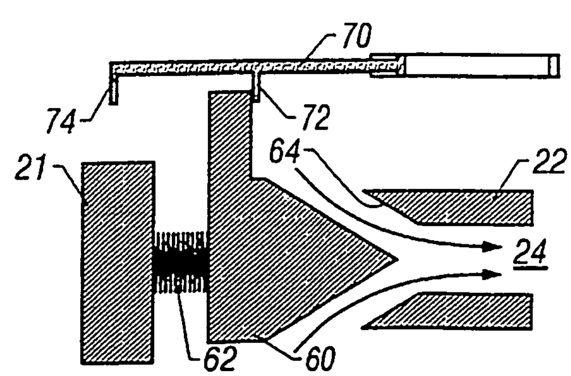

FIG. 12D

SAND SCREEN WITH ACTIVE FLOW CONTROL

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to the art of well completion methods and equipment for the production of hydrocarbon fluids. More particularly, the invention relates to methods and apparatus for downhole regulation of hydrocarbon fluid production rates.

DESCRIPTION OF RELATED ART

Bottom hole well tools are exposed to extremely abrasive operating conditions. As hydrocarbon fluid is released from the naturally occurring in situ formation, sand, rock and other abrasive particles are drawn with it. In deeper wells where the in situ pressures are extremely high, the production pressure drop between the formation and the flow bore of the production tube is correspondingly high. Such high pressure differentials in the presence of a highly abrasive fluid rapidly erodes the production control tools. Fluid velocity through and over the tool surfaces, elements and apertures is an exponential function of the pressure differential drive. Hence, high pressure differentials translate to high fluid velocities. High velocity fluids entrained with abrasives translates to high rates of erosion, wear and failure.

Earth formation pressures and fluid production are not, however, fixed properties. Both of these properties change over time. Moreover, the changes are not necessarily linear or in predictable directions. The changes may be abrupt, irregular and/or fluctuating. In cases of an elongated production zone, often horizontal, the production properties may change in one section of the producing zone differently than those in another section of the same producing zone.

Although downhole tools for limiting the production rate of a production zone are known to the prior art, such tools have a fixed configuration. Production flow rate adjustments are usually made at the surface. Downhole flow rate adjustment is accomplished by removing the production tools from the well bore and replacing a first fixed flow rate tool with a second fixed flow rate tool of different capacity.

It is, therefore, an object of the present invention to provide active flow control, from the surface, over production from gravel pack installations through sand control screens down to an individual screen.

Another object of the invention is provision of means to regulate the inflow of fluids from a long, horizontal petroleum reservoir to maximize production.

Also an object of the present invention is provision of means to terminate production flow from a production screen or to divert flow from one screen to another within the screen assembly.

A further object of the invention is provision of means to adjust the production flow rate of a well.

SUMMARY OF THE INVENTION

These and other objects of the invention are served by a tool that is associated with a production sand screen to channel the screened production flow through a flow control zone. Within the flow control zone is a static flow control device that reduces the fluid pressure differential over an extended length of flow restrictive channel. At either end of the flow control device are transverse flow apertures disposed between the flow control zone and the internal flow bore of the primary production tube.

The apertures are flow controlled as either opened or closed completely. This operational set allows three flow states. When the apertures upstream of the flow control device are closed and those downstream are open, all production flow from the associated screen must pass through the flow control device. In doing so, the flow stream is required to follow a long, helical path. Traversal of the flow control device dissipates the pressure of state within the fluid thereby reducing the pressure

differential across the production tool. The energy potential of the pressure is converted to heat.

When apertures upstream of the flow control device are open and those downstream are closed, production flow is shunted directly from the flow control zone into the internal flow bore of the primary production tube. This operational state permits the particular tool to run "open choke" but not necessarily all tools in the formation.

The third flow state closes both apertures to terminate all production flow from the associated screen.

A preferred embodiment of the invention provides a cylindrical tool mandrel within the internal bore of a production tube that forms an annular flow channel along the tube axis. Axially displaced from the screen inflow area, is a circumferential band of longitudinal stator columns that span radially across the flow channel annulus to funnel the annulus flow through gates between the stator columns. Further displaced axially along the flow channel annulus is a helically wound wall that also spans radially across the flow channel annulus. This helically wound wall is one embodiment of a static flow control device.

Two sets of flow apertures through the mandrel wall section link the annular flow channel with the internal bore of the production tube. A first

aperture set is positioned axially displaced from the static flow control device opposite from the band of stator columns. A second aperture set is positioned axially displaced from the band of stator columns opposite from the flow control device. An axially slideable ring substantially encompasses the mandrel at an axial location adjacent to the stator columns opposite from the static flow control device. The ring is axially displaced by one or more hydraulic cylinders. From one annular edge of the ring projects a number of gate plugs. The number of plugs corresponds to the number of gates. The gate plugs overlie the second set of flow apertures at all positions of axial displacement but one.

At a first, axially stroked extreme position of the ring, the second flow aperture set is open to facilitate direct and unrestricted flow of production flow from the channel annulus into the internal bore.

At an intermediate axial position of the ring, the plugs close the gates between the stator columns thereby blocking flow to the first flow aperture set. Also at this intermediate setting, the gates block flow through the second set of apertures by their lapped, overlay location. Consequently, at the intermediate setting, no flow from the channel annulus is admitted into the inner bore.

At a second axial extreme position, the plugs are withdrawn from the gates to allow flow through the

static flow control device and into the first set of flow apertures. However, at the second axial extreme position the plugs continue to block flow through the second set of flow apertures. Consequently, the flow stream is required to traverse the static flow control device to reach the inner production tube bore.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages and further aspects of the invention will be readily appreciated by those of ordinary skill in the art as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings in which like reference characters designate like or similar elements through the several figures. Briefly:

FIG. 1 is an environmental schematic of the invention;

FIG. 2 is a cross-sectional view of the invention in a flow restrictive setting;

FIG. 3 is a cross-sectional view of the invention in a flow obstructing setting;

FIG. 4 is a cross-sectional view of the invention in a free-flow setting;

FIG. 5 is a plan view of the invention mandrel in the restrictive flow setting;

FIG. 6 is a plan view of the invention mandrel in a flow obstructing setting;

FIG. 7 is a plan view of the invention mandrel in a free-flow setting;

FIG. 8 is a solenoid valve controlled embodiment of the invention;

FIG. 9A is a cross-sectional view of a special case solenoid valve pintle in a normal operating mode;

FIG. 9B is a cross-sectional view of a special case solenoid valve pintle in a normal operating mode;

FIG. 10A is a hydraulic control schematic in the hydraulic fluid flow blocking mode due to production flow temperature;

FIG. 10B is a hydraulic control schematic in the hydraulic fluid flow open mode due to production flow temperature;

FIG. 11A is a production valve control system responsive to a shape memory alloy driver to open a production flow transfer aperture;

FIG. 11B is a production valve control system responsive to a shape memory alloy driver to close a production flow transfer aperture; and,

FIGS. 12A through **12D** illustrate the operational sequence of an automatic, thermally controlled valve pintle.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With respect to the environmental schematic of **FIG. 1**, a production tube **10** is positioned within a wellbore casing **12** to provide a continuous flow conduit to the surface for a flow of fluids extracted from a subterranean earth formation. Along a formation fluid production zone, the casing is perforated by apertures **14** for facilitation of formation fluid flow into an outer production

annulus **18** between the interior wall of the casing and the exterior wall of the production tube. Longitudinally, the production annulus **18** may be delimited by an outer packer **16**.

Below the outer packer **16**, the production tube **10** includes one or more sand screens **20** linked by flow control housings **21**. Internally of the screens and flow control housings is a flow control mandrel **22**. A flow control annulus **23** is accommodated between the interior walls of the flow control housings **21** and the exterior walls of the mandrel **22**. The continuity of the flow control annulus **23** may be interrupted between sand screens **20** by an inner packer **29**.

Referring now to the partial cross-section of **FIG. 2** and the schematic plan of **FIG. 5**, it is seen that the wall of mandrel **22** is penetrated by two circumferential sets of flow apertures **24** and **26**. Between the apertures **24** and **26**, the outer mandrel surface is profiled by surfaces that extend radially out to juxtaposition with the interior surface of the housing thereby substantially confining all fluid flow along the flow control annulus **23**.

A first exterior profile on the flow control mandrel **22** is a circumferential band of substantially uniformly spaced stator columns **30**. Between the stator columns **30** are flow gates **32**. A second exterior profile on the flow control mandrel **22** is a

static flow control device **28** comprising a helically wound channel between parallel walls.

Proximate of the first circumferential set of flow apertures **24** is a circumferential set of gate plugs **36** extending from one edge of a base ring **34**. The opposite base ring **34** edge is attached to one or more hydraulic, for example, struts **38**.

Representatively, a strut **38** may comprise a cylinder **40** secured to the surface of mandrel **22** and a piston rod **41** secured to the opposite edge of the base ring **38**. The rod **41** may be extended axially from the cylinder **40** to axially reposition the base ring **38** and gate plugs **36** by manipulations of pressurized hydraulic fluid in one or two hydraulic fluid conduits **42** and **43**. Extensions of the conduits **42** and **43** to the surface enable these manipulations from the surface if required. Downhole hydraulic fluid power control may also be accomplished by numerous other means and methods known to the active practitioners of the art.

As may be observed from a comparison of **FIGS. 5, 6** and **7**, the rod **41** is stroked to provide the base ring **38** and projecting gate plugs **36** an intermediate position (**FIG. 6**) between two extreme positions (**FIGS. 5** and **7**). At the **FIG. 5** position, production flow may travel along the control annulus **23**, around the gate plugs **36**, through the gates **32** between stator columns **30**, and along the helically wound flow channel of the static control device **38** into the apertures **26**. From the apertures **26**, the fluid enters the inner bore **11** of the production tube to

be lifted or driven by expanding gas to the surface. To be noted from **FIG. 5** is the overlaid relationship of the apertures **24** by the gate plugs **36** thereby effectively blocking fluid flow into the apertures **24**.

When the gate plugs **36** are shifted to the intermediate position shown by **FIG. 6**, the plugs **36** fill the flow channel space **32** between the stator columns **30** thereby blocking flow into the static flow control device **28**. Consequently, no flow reaches the apertures **26** for flow into the inner bore **11**. Moreover, gate plugs **36** continue to overlie the aperture set **24** and block fluid flow therethrough.

FIG. 7 illustrates the alternative extreme position whereat the gate plugs **36** enter the gates **32** fully thereby continuing the blockage of flow into the apertures **26**. However, as the gate plugs **36** move deeper into the gates **32**, the apertures **24** are uncovered. At this arrangement, only a minimum of flow resistance is imposed as the production flow stream finds its way to the surface.

The alternative embodiment of the invention depicted by **FIG. 8** controls the opening and closing of apertures **24** and **26** with electrically actuated solenoid valves **44** and **46**. For unrestricted flow, valves **44** would be opened and valves **46** closed. For maximum flow resistance, Valves **44** would be closed and valves **46** opened to force the production flow

through the static flow restriction device **28**. For zero flow, of course, both valves **44** and **46** are closed.

As a permutation of the **FIG. 8** embodiment, **FIGS. 9A** and **9B** illustrate a solenoid valve **48** having an electrically energized winding **50** secured in the housing **21** for selectively translating a pintle **52** into or out of a flow aperture **24** or **26**. Distinctively, the pintle **52** is centrally hollow. The hollow core **54** of the pintle stem is closed by plug **58** at the end that penetrates into the inner flow bore **11**. However, the hollow core is open to the control flow annulus **23** by apertures **56** when the pintle **52** is at the closed aperture **24** position. In the event of power or control failure of a nature that prevents a desired opening of a closed valve **48**, a restricted by-pass flow may be obtained by deployment of a shear dart from the surface along the inner bore **11** to mechanically break the end of the pintle stem and expose the hollow core **54**.

As the flow of the production fluid transfers energy to the flow control equipment, frictional heat is generated. Consequently, the equipment temperature bears a functional relationship to the production flow rate. Based on the fact that operating temperatures of flow control devices change as a function of flow rates, automated downhole control of such devices may be accomplished with valves that respond operationally to the temperature changes. **FIGS. 11A** and **11B** illustrate one embodiment of this

principle wherein a valve pintle element **60** is operatively driven by a shape memory alloy **62** into cooperative engagement with a valve seat **64** to directly control production flow through an aperture **24**. **FIG. 11A** schematically illustrates the valve elements in a production flow condition wherein the flow rate through the flow aperture **24** is insufficient to generate heat at a rate that is sufficient to expand the shape memory alloy valve driver **62**. In contrast, **FIG. 11B** schematically illustrates a non-flow condition wherein the shape memory alloy driver **62** has expanded due to excessive heating and pushed the pintle 60 into engagement with the aperture **24** seat **64**.

The invention embodiment of **FIGS. 12A-12D** modifies the foregoing control structure further with a mechanically controlled override. In this design, the valve pintle **60** includes, for example, an engagement tab **66** that cooperates with shift fingers **72** and **74** that depend from a selectively stroked hydraulic strut. **FIG. 12A** schematically illustrates the production flow condition in which the shape memory alloy driver **62** is contracted and the pintle **60** is withdrawn from the valve seat **64**. The strut **70** is at an intermediate position with the shift finger **74** in close proximity with the engagement tab 66. **FIG. 12B** schematically illustrates a condition change wherein flow generated heat has expanded the alloy driver **62** and caused the pintle **60** to be translated into closure contact with the valve seat **64**.

Represented by **FIG. 12C** is a disfunction condition wherein the alloy driver **62** has cooled and contracted but the pintle **60** has not drawn away from the seat **64** to open the aperture **24**. **FIG. 12D** schematically illustrates the override of the shape memory alloy **62** with an engagement of the pintle tab **66** by the strut finger **72** to forceably push the pintle **60** away from the valve seat **64**.

The inventive concepts represented by **FIGS. 10A** and **10B** apply the concepts of automatic flow regulation with shape memory alloy control elements to the hydraulic control lines **42** and/or **43** in the **FIG. 2** embodiment. **FIG. 10A** represents a check valve control **80** in the hydraulic strut power line **42**. A ball closure element **82** is pressure differentially biased against the valve seat **84** to block flow through the conduit **42** into the strut **38**. The closure condition prevails while the shape memory alloy driver **86** is cool and contracted. When the flow control elements are sufficiently heated by excessive flow velocity, the memory alloy driver **86** expands against the disengagement probe **88** to push the ball **82** off the seat **84** and allow hydraulic flow into the strut **38**. Resultantly, the strut rod **41** and gate plug **36** are displaced in a direction to restrict or terminate the excessive flow.

Modifications and improvements may be made to these inventive concepts without departing from the scope of the invention. The specific embodiments shown

and described herein are merely illustrative of the invention and should not be interpreted as limiting the scope of the invention or construction of the claims appended hereto.

CLAIMS

1. A method of regulating the flow of hydrocarbon fluid from a producing zone into a production well, said method comprising the steps of:
   a. providing a fluid production tube in a wellbore having a formation fluid production zone, said production tube having a production flow bore therein;
   b. providing an intermediate fluid flow channel within said production tube between said production zone and said production flow bore;
   c. providing a static flow restriction within said intermediate channel;
   d. providing a first flow aperture between said intermediate channel and said production flow bore downstream of said flow restriction;
   e. providing a second flow aperture between said intermediate channel and said production flow bore upstream of said flow restriction; and,
   f. selectively obstructing fluid flow through either or both of said flow apertures.

2. A method as described by claim 1 wherein said flow apertures are selectively opened and closed.

3. A method as described by claim 1 wherein fluid flow through said first aperture is obstructed

by a selective obstruction of flow through said flow restriction.

4. A well tool for regulating the flow rate of fluid from an earth producing zone, said tool comprising:

a. a well fluid production tube having a production flow channel therein and a production fluid flow screen for passing fluid from said producing zone into said production flow channel;

b. an intermediate flow channel between said flow screen and said production flow channel;

c. a static flow restriction in said intermediate channel;

d. a first fluid flow aperture between said intermediate flow channel and said production flow channel disposed downstream of said static flow restriction;

e. a second fluid flow aperture between said intermediate flow channel and said production flow channel disposed upstream of said static flow restriction; and

f. a selectively positioned flow obstruction for substantially preventing fluid flow through either or both of said flow apertures.

5. A well tool as described by claim 4 wherein said selectively positioned obstruction is driven by a shape memory alloy.

6. A well tool as described by claim 4 wherein said selectively positioned obstruction is a solenoid valve operator respective to said flow apertures.

7. A well tool as described by claim 6 wherein said valve operator comprises a flow by-pass element.

8. A well tool as described by claim 7 wherein said by-pass element comprises a valve stem conduit having an open entry aperture in said intermediate flow channel and a plugged exit aperture in said production flow channel.

9. A well tool as described by claim 4 wherein said flow obstruction comprises a fluid flow gate within said intermediate flow channel for obstructing fluid flow into said flow restriction.

10. A well tool as described by claim 9 wherein fluid flow through said fluid flow gate is controlled by a selectively positioned plug.

11. A well tool as described by claim 10 wherein said selectively positioned plug also obstructs fluid flow through said second flow aperture.

12. A method of regulating the flow of production fluid from a fluid producing zone into a production conduit comprising the steps of:
    a. providing first and second fluid flow routes for production fluid from a producing zone into a production conduit;
    b. providing greater resistance to flow along said second flow route relative to flow along said first flow route; and,
    c. providing a first selectively engaged flow obstruction along said first flow route.

13. A method as described by claim 12 further providing a second selectively engaged flow obstruction along said second flow route.

14. A method as described by claim 12 wherein said first and second flow routes extend from an intermediate fluid flow channel between said fluid producing zone and said production conduit.

15. A method as described by claim 12 wherein said first flow obstruction is manually engaged.

16. A method as described by claim 12 wherein said first flow obstruction is automatically engaged.

17. A method as described by claim 12 wherein said first flow obstruction is automatically engaged as a function of a production fluid flow rate.

Application No: GB 0201645.9
Claims searched: 1 to 17

20

Examiner: Matthew Perkins
Date of search: 17 May 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): E1F: FLE, FLF, FLH, FLJ, FLK, FLM

Int Cl (Ed.7): E21B

Other: Online: WPI, EPODOC, PAJ

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2361017 A	(PUMP TOOLS LTD.) See abstract and figures	-
A	GB 2351748 A	(MAERSK) See abstract, figures and page 2 line 23 to page 5 line 21.	-
A	GB 2314866 A	(BAKER HUGHES INC.) See figures, abstract and page 4 line 6 to page 5 line 17.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.